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(54) Secure optical data systems

(57) In an optical fibre data transmission system, detection of an unauthorised tap is achieved by applying to a fibre conveying the data, a standing optical signal whose amplitude  $P$  is considerably greater than the amplitude  $P_s$  of the data. This depresses the sensitivity of the system receiver to an extent at which the receiver noise has as its dominant component the shot noise in the signal. Thus the reduction in received power due to a tap is readily detectable.

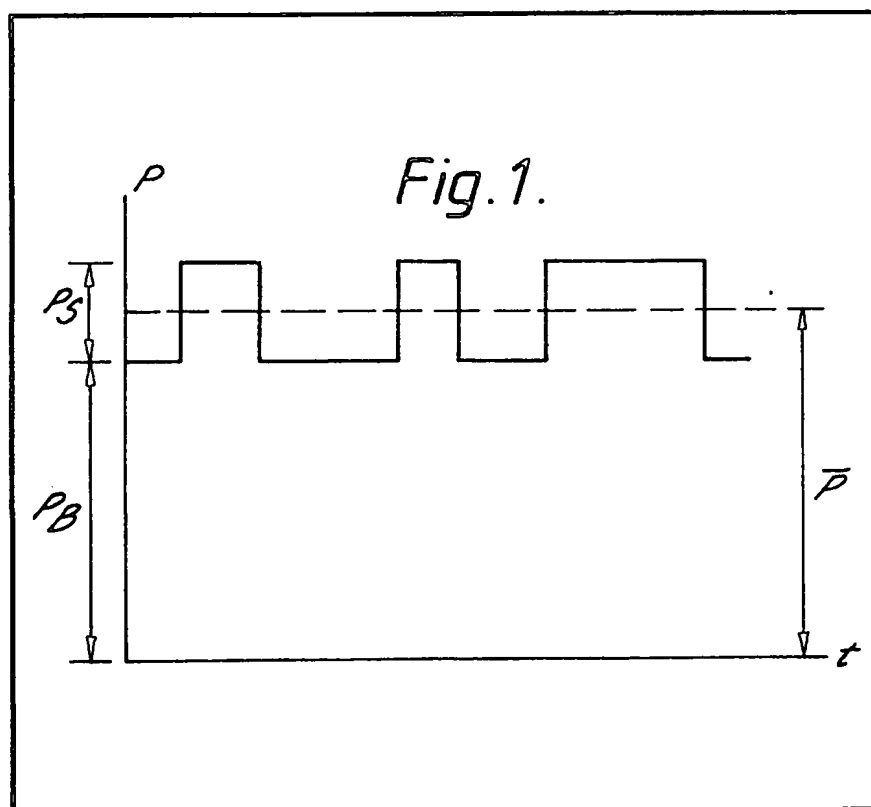


Fig. 1.

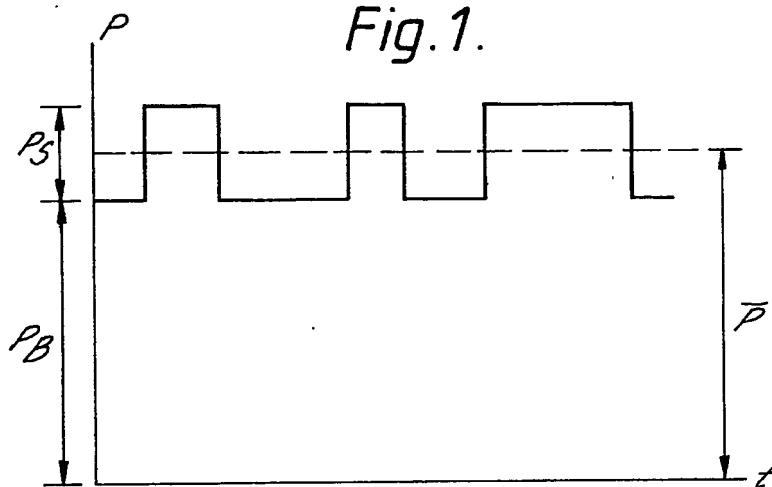


Fig. 2.

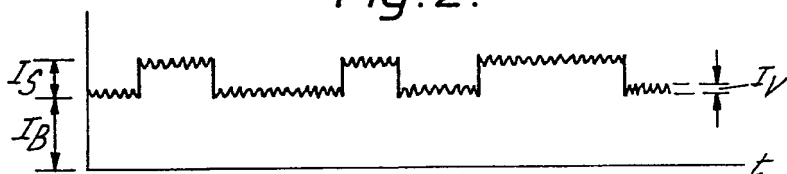


Fig. 3.

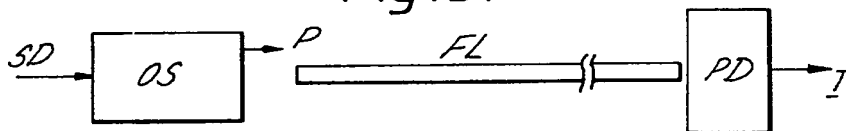
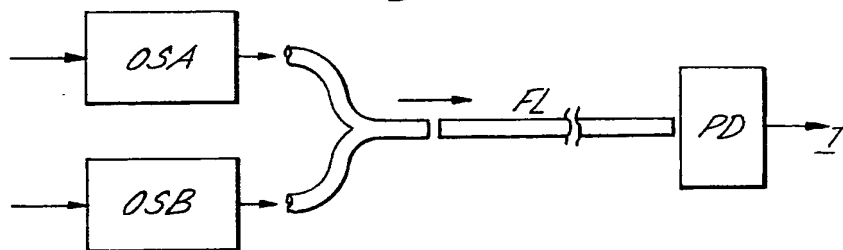


Fig. 4.



## SPECIFICATION

## Secure optical data systems

- 5 This invention relates to optical fibre data transmission systems.

With such systems intended for use in high security environments it is desirable that any unauthorised tapping of the optical fibre links should be detectable, e.g. as a result of a decrease in the signal volume at the receiving end. Naturally it is the designer's intention to make it as difficult as possible for a tapper to get any light from the fibre without detection, but if the prevention of tapping is impossible it is desirable to make sure that an unauthorised tap to be intelligible will have to remove such a large amount of light as to make detection of the tap easier.

- 20 According to the invention there is provided an optical fibre data transmission system, in which data to be transmitted is conveyed by intensity modulation of the light, in which a standing optical signal whose magnitude is substantially greater than the magnitude of the data to be transmitted is added to the data signal to be conveyed, in which, due to the standing optical signal having a magnitude greater than that of the data signal, the dominant component of receiver noise is that due to the shot noise of the received optical signals, so that the sensitivity of the receiver is limited, and in which for an unauthorised tap to the fibre link to be effective a substantial proportion of power is removed, so that the reduction in power, both of the data signal and of the standing signal, which reaches the system receiver is substantial, so that the existence of such a tap, is readily detectable at the system receiver.

An embodiment of the invention will now be described with reference to the drawing, in which

- Figure 1 is an explanatory waveform diagram for signals transmitted in a system embodying the invention.

Figure 2 is a diagram corresponding to Fig. 1 of the signals as received.

- Figures 3 and 4 show two ways of feeding signals and other light into an optical fibre link in a system embodying the invention.

We now consider the underlying theory on which the present system is based.

- The power required by the receiver is  $P$  (dBm), in which case the power in the fibre near the transmitter (where it is easier to tap) is  $(P + A)$ , where  $A$  (dB) is the attenuation of the fibre and couplings. The power needed by a tapper is  $(P - M - I - D)$ , where  $M$  is the power margin allowed by the system designer for degradation of the system,  $I$  is an "intelligibility margin" and  $D$  represents the difference in quality between the system's receiver and the tapper's receiver (positive if the tapper's receiver is more sensitive than the sys-

tem's receiver). The value of  $I$  represents the fact that whereas the system normally has to work on a quality of signal which is comfortable or convenient for the user, the tapper can manage with a barely intelligible signal.

- 70 The result of the above considerations is that the signal required by the tapper can be as low as  $(A + M + I + D)$  dB below the signal in the fibre near the transmitter. Ideally

- 75  $A = M = D = 0$ , and if  $I$  can be made as low as, say 3dB, then even a perfectly efficient tapping procedure would cause half the power to be dropped as "seen" by the system receiver. This is easily detectable since the

- 80 receiver signal must also be unintelligible. In practice the attenuation  $A$  can be very low, and so can  $M$  with stable components. The value of  $I$  also tends to be low—of the order of a few dB—in digital systems, and

- 85 can be deliberately reduced by coding. The present system seeks to reduce the value of  $D$ , i.e. to reduce the difference in quality of the system's receiver and the tapper's receiver. That is, if the two receivers have similar sensitivities the presence of the tapper's receiver causes a reduction in the light which reaches the system receiver which cannot help but be noticed.

- The photodetector used in the system receiver may not be as sensitive as that available to the tapper for two reasons:

- (a) the most sensitive type may be unsuitable for use in the system on the grounds of expense, stabilisation requirements on biasing, etc., objections which may not be relevant to the tapper.

- (b) Technical improvements in available detectors may occur after the system has been installed.

- 105 If the detector is working on the quantum limit (shot noise in signal), then it is fundamentally impossible to improve the detector, so  $D \leq 0$ . However, especially in digital systems (where  $I$  can be lower than would be needed for an analogue system) it is not within the present state of the art to approach closer than 10dB to the quantum limit. Even to achieve this would need the use of an avalanche photo-diode.

- 115 The solution to the above problems, according to the invention is to add a standing optical power transmission to the intensity modulated signal, as indicated rather schematically in Fig. 1. This added standing power is typically many times more intense than is the mean signal power. Thus in Fig. 1 the standing power referred to is represented in Fig. 1 by the applied bias power  $P_b$ , which can be seen is considerably greater than the peak-to-peak signal amplitude  $P_s$ , the signal waveform being shown as digital as an example. Mean power  $\bar{P}$  is, to a good approximation, equal to  $P_b$  if  $P_b$  is considerably greater than  $P_s$ .

- The received optical power is  $\alpha P$ , where  $\alpha$  represents path loss. The result is that the

dominant component of receiver noise is shot noise in received optical power, so that a practical photo detector can be quantum limited. This is a fundamentally different technique from the application of a masking noise signal as will become apparent in the course of the following discussion.

We now refer to Fig. 2: at the receiver output,  $I_s$  is proportional to  $\alpha P_s$ , and  $I_b$  is proportioned to  $P_b$ .

For a quantum ideal receiver, we have:

$I_n$  is proportional to  $\sqrt{P} \approx \sqrt{P_b}$

where  $I_n$  is noise current, and  $\alpha$  (as already indicated) is the total path loss between the optical transmitter and the optical receiver.

$$\therefore \frac{S}{N} = \frac{I_s^2}{I_n^2} = \alpha \frac{P^2}{P_b}$$

Thus the actual signal to noise ratio ( $S/N$ ) at the detector is almost as good as the fundamental limit set by shot noise in signal. If the taper receives half the signal optical power and with it half the standing light that is available to the system receiver, then the signal current is reduced by a factor of 2, while the shot noise is reduced by a factor of  $\sqrt{2}$ . Hence the fundamentally available  $S/N$  ratio is halved, and no improvement is possible using a better optical receiver. This is by contrast with the situation with an added noise signal, where both signal and noise would be reduced in proportion to the tapped power and the  $S/N$  ratio would be unchanged.

The above-described arrangement is effective if the standing light and the signal are carried in the same modes in the fibre, but it can be made more effective if the standing light is carried separately in such a way that the system receiver which has access to the fibre end receives a lower portion of the standing light than a taper having improper access to the side of the fibre. Thus the disadvantage under which the taper operates is increased.

To emphasize the distinction between the present arrangement and the mere use of a masking noise signal, a further point is significant. If the standing light (or "guard signal") was used as a simple masking noise signal, a taper would be able to sort out the masking effect merely by comparing the outputs of two detectors so positioned along the fibre as to give different ratios of signal and masking noise. With the present technique, such a comparison operation would be of no help since the limitation produced by this technique comes from the statistical effect, noted only at the receiver, that the actual number of photons detected in any time slot has a probability distribution depending on the mean

number of photons.

Another feature of the present technique is that the combined signal may in some cases be more suitable for a dropped power alarm than the alternative of using only signal power.

The advantages of this are:

(i) mean power can be independent of signal.

(ii) higher power.

(iii) the dominant standing light may be easier to stabilise at source than a time-varying signal.

(iv) if the standing mode is conveyed by outer modes in a complex (e.g. graded index or multilayer) fibre, these outer modes may be more sensitive to interference than the inner signal.

We now refer to the simplified diagrams of

Figs. 3 and 4. In Fig. 3 we see an optical source OS which feeds its output P to the optical fibre link FL, using a laser or light-emitting diode arrangement. This source OS receives the signals to be conveyed over a signal drive input SD, and applies these signals, plus the standing light, to the output P. At the receiving end a photo-detector PD responds to the light arriving over the fibre link FL, and extracts therefrom the signal, which it applies to the output I.

Fig. 4 is similar except that here two optical sources OSA and OSB are combined via a coupler C to drive the fibre link FL.

## 100 CLAIMS

1. An optical fibre data transmission system, in which data to be transmitted is conveyed by intensity modulation of light, in which a standing optical signal whose magnitude is substantially greater than the magnitude of the data to be transmitted is added to the data signal to be conveyed, in which, due to the standing optical signal having a magnitude greater than that of the data signal, the dominant component of receiver noise is that due to the shot noise of the received optical signals, so that the sensitivity of the receiver is limited, and in which for an unauthorised tap to the fibre link to be effective a substantial proportion of power is removed, so that the reduction in power, both of the data signal and of the standing signal, which reaches the system receiver is substantial so that, the existence of such a tap is readily detectable at the system receiver.

2. An optical fibre data transmission system, substantially as described with reference to the accompanying drawings.

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